COVERT NIGHT ATTACK AVIONICS

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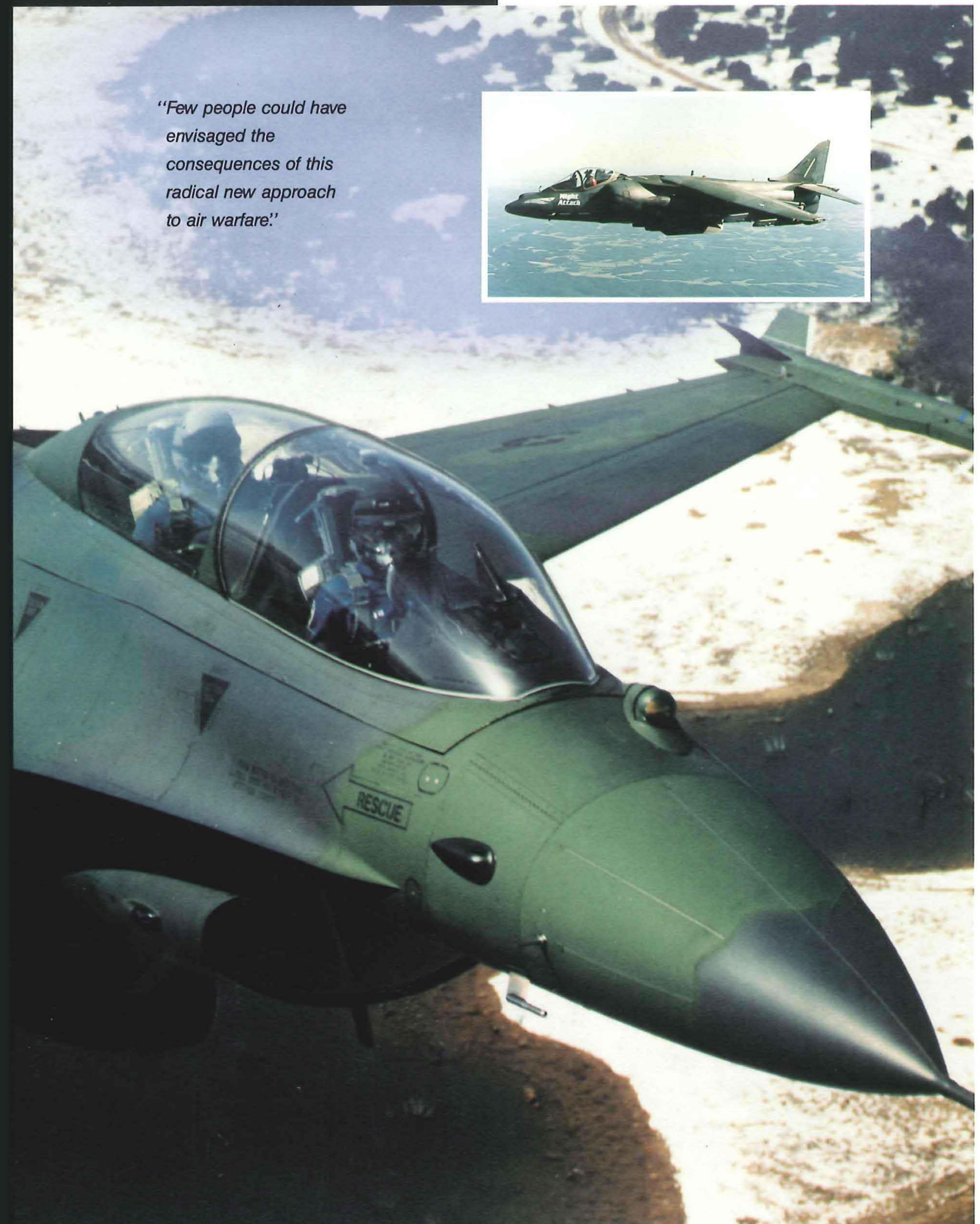


"Few people could have envisaged the consequences of this radical new approach to air warfare."

By J F Fisher

The development of air power has revolutionised the conduct of tactical warfare. However, until recently its use outside daylight hours was very limited, particularly since aircraft for operational reasons need to fly at very low altitudes, generally below 500 feet. Obviously this is both difficult and dangerous without specialised avionics equipment. The requirement to operate at low level by night however is clear; in recent years land forces have increased their emphasis on movement and operations by night, in order to avoid attack and reconnaissance by enemy aircraft. This is particularly true of the Warsaw Pact forces which have specialised in the development of night operations with armour. The first real night low level capability came with the development of terrain following radar (TFR). The F-111, and later the Tornado aircraft, offered the ability to conduct low level operations at night using the returns from TFR to programme the flight control system and to contour fly at heights down to 200 feet. Impressive as these systems are, they do have a number of limitations. They are active systems, which can be detected, jammed and intercepted. In these days of increasing ESM and ECM sophistication, this is a major problem. They are also very limited in their ability to locate and identify hostile targets. Unless these targets have distinctive radar characteristics, the aircraft is limited to attacking targets with known coordinates. Finally they are both expensive and complex.

The last few years have seen the emergence of a simpler and cheaper alternative to TFR; covert low level avionics systems offer the ability to operate fixed wing attack aircraft at very low level by day and by night in VFR and limited IFR conditions. GEC Avionics pioneered the development of this equipment and its operating techniques in conjunction with a number of UK and US agencies. Prime amongst these were the Royal Aerospace Establishment at Farnborough, the US Marine Corps, the US Navy and General Dynamics. This paper briefly describes these equipments, their evolution and integration into a total system and how such an integrated system can be used to produce a revolutionary new offensive capability.

An integrated covert system needs to have three main capabilities if it is to provide the crew with the information it needs to operate safely and effectively (Figure 1). The first and most obvious requirement is night vision. The crew needs to be able to see out with sufficient field of view and resolution to be able to contour fly at low level, manoeuvre freely through all types of terrain and to acquire and recognise potential targets. However such a night vision system is not in itself sufficient to provide a full operational capability. The crew must also be able to navigate with sufficient accuracy. Since pilot inputs to the navigation system are limited, considerably greater accuracy is required by night than by day, and the positional information must be presented to the pilot in a form which he can assimilate. Obviously the use of a paper map in a darkened cockpit at night is very limited. The third corner of the triangle is to provide the pilot with systems to avoid the ground and vertical obstructions

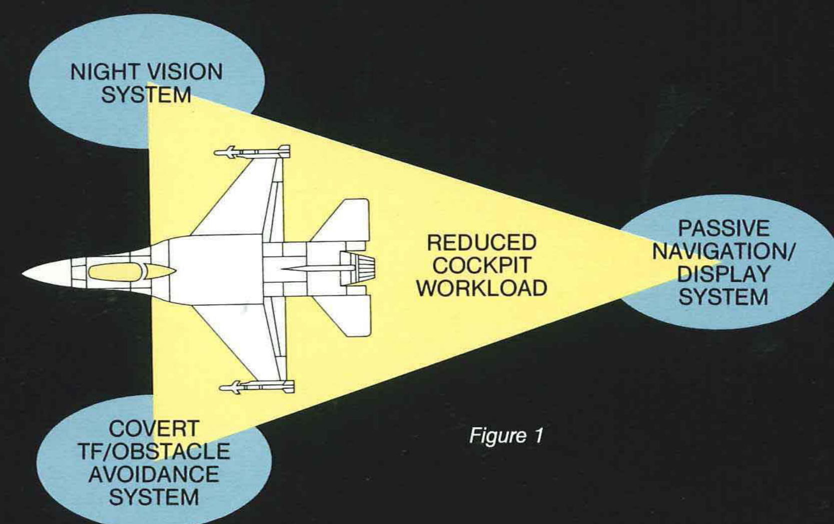


Figure 1

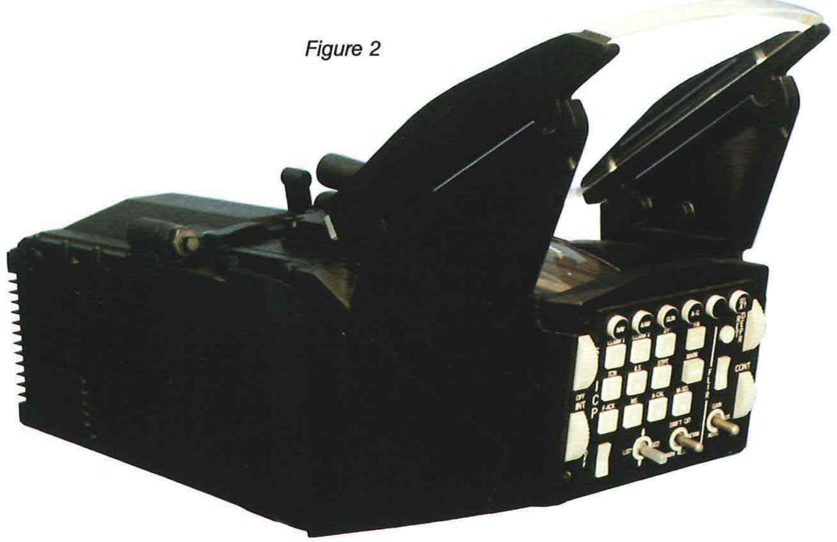
even in conditions where he has difficulty in seeing them with his electro optical sensors. The obvious requirement is to avoid high tension cables and their pylons. No conventional electro optical sensor has sufficient resolution and discrimination to reliably detect and display wires. High tension cables represent the greatest threat to safe low level flight, both by day and by night. Conventional mechanisms for detecting such cables have several disadvantages. They may be detectable, and they do not all offer a sufficient probability of cable detection.

It can be readily seen that such an integrated system has to provide the crew with large amounts of visual data. The other vital ingredient to safe covert operation is the means to present that data to the pilot in a form which he can readily accept. The key to safe low level operation is pilot workload. The systems described here were evolved with the specific aim of reducing crew workload by night to a level which is little greater than that for normal day operation.

Night Vision

The first flight trials used a GEC Sensors (then Marconi Avionics) low light TV (LLTV) sensor, hard-mounted into the nose of the RAE Hunter aircraft, displaying its imagery on a head down display in the cockpit. It rapidly became obvious that the imagery had to be related to the pilot's outside world scene to be fully useable. The first raster head up displays were therefore developed for use on the US Navy A-7 Corsair and the RAE Hunter. With the RAE Hunter, the electro optical imagery was displayed on the raster HUD, scaled 1:1 and collimated at infinity. Since the imagery overlaid the outside world scene, the pilot was able to fly at low level using his normal day flying techniques. As electro optical technology progressed, the LLTV was replaced by a forward looking infra red (FLIR) sensor. This had the advantage of operating independently of ambient light level, and of solving the other major problem, that of target acquisition. Thermally significant targets, such as tanks and armoured vehicles, are clearly identifiable on the FLIR imagery because of their thermal characteristics. Provided an adequate field of view image was displayed to the pilot, trials demonstrated clearly that he could fly consistently at high speed and low level following the contours of the ground in a straight line. Flight trials had indicated that the minimum instantaneous field of view for the head up display should be 20° in azimuth and 15° in elevation. Any smaller field of view restricts the pilot's ability to orientate himself consistently. It should be noted that the requirement is for a large instantaneous HUD field of view rather than a sensor or HUD total field of view. In other words, it is the image that the pilot can see at any one time without moving his head which counts, not the total image available if he moves his head around.

Figure 2



While this combination of raster HUD (Figure 2) and FLIR gives good contour flying and target acquisition capabilities, it does not allow the pilot to manoeuvre his aircraft sufficiently for tactical operations. The restricted field of view of the FLIR sensor and display effectively restricts the pilot to an approximately 45° angle of bank. The simplest solution to this problem turned out to be the use of Night Vision Goggles (NVGs) mounted on the pilot's helmet. Initial trials on the RAE Hunter in 1980 demonstrated clearly that a pilot could use conventional NVGs alone to fly a high speed, fixed wing aircraft at heights down to 200 feet or less.

Although the resolution of the NVGs is less than half that of the FLIR, the ability to look around and the natural appearance of the image offers full low level capability. The main restrictions on the use of conventional NVGs are the limited light levels in which they can operate, their inability to discriminate targets and the safety and comfort implications of having a relatively heavy piece of equipment mounted on the front of the pilot's helmet. In practice, the combination of the raster HUD and FLIR with the NVGs proved to be a most effective combination. The pilot uses the NVGs to fly at low level and to manoeuvre whenever light levels permit, while the FLIR/HUD system gives high resolution image ahead of the aircraft independent of light levels with full target acquisition capability (See Figure 3).

Conventional NVGs proved to have one major disadvantage. The pilot views the FLIR image on the raster HUD through the NVGs.

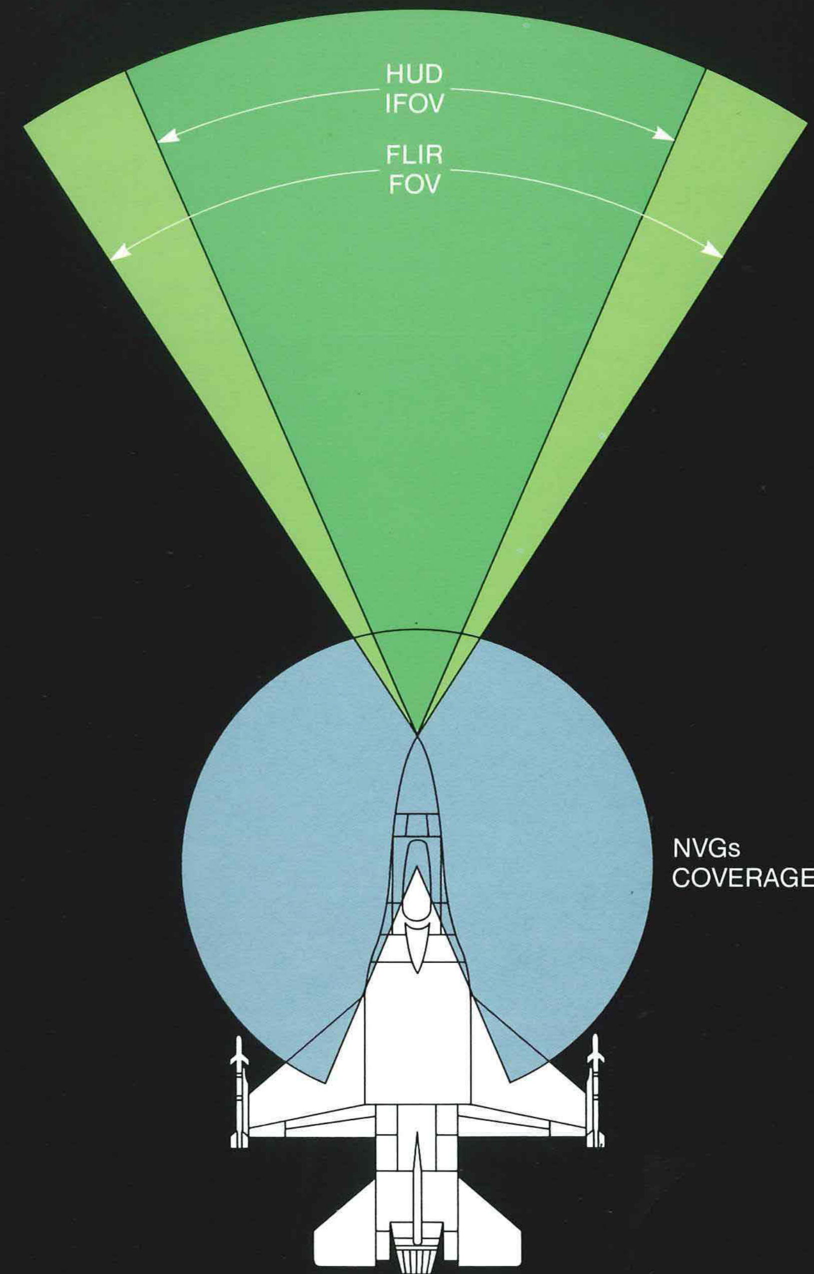


Figure 3

Since the resolution of the NVGs is less than half that of the FLIR/HUD combination, the result is a considerable degradation in the pilot's low flying and target acquisition capability. In 1980, GEC Avionics started the development of the Cats Eyes NVG system (See Figure 4) which displays the low light image from the image intensifier tubes on clear glass see-through combiners in front of each eye. The result is that the pilot is able to see his cockpit instruments

Figure 4

and his HUD with no noticeable deterioration in resolution, while retaining the advantages of NVG low level operation.

An effective alternative to the combination of NVGs, FLIR and HUD was demonstrated on the Falcon Eye program by General Dynamics (See Figure 5). GD mounted a fully gimballed wide angle FLIR system in the nose of the aircraft which could be steered to look in almost any direction. An electro magnetic head position sensing system detects the direction in which the pilot is looking and turns the FLIR sensor in the same direction. The imagery from the FLIR is then displayed on a biocular helmet mounted display mounted on the pilot's helmet. For the Falcon Eye system, the FLIR was provided by Texas Instruments and the biocular helmet mounted display by GEC Avionics. Initial flight trials on Falcon Eye proved conclusively that a monocular helmet mounted display did not provide adequate pilot orientation for night low level operation. Although this system is more complex and expensive than the HUD/FLIR/NVG system, it has the advantage of offering a high resolution image wherever the pilot looks, and of offering a target acquisition capability at all angles off the aircraft's axis. It is particularly well suited to the pop-up and tip-in type of air-to-ground attack, and has potential for air-to-air operation.

Figure 5

Figure 6

The disadvantage of mounting NVGs on a pilot's helmet have already been discussed. The successor to fixed wing NVGs has already been developed (See Figure 6). On this integrated night vision helmet, the complete optical system, including image intensifier tubes and transparent combiners, have been integrated into the pilot's helmet. This helmet, which is due to start flight trials early in 1990, has already proved to be fully compatible with windblast and ejection requirements. The weight and centre of gravity have been so improved that it is comparable to wearing a conventional helmet, with negligible restriction to the pilot's normal field of view. One other version of this integrated helmet will combine the NVG capability with a full binocular display. By combining the images from two CRTs with those from two image intensifier tubes, GEC Avionics can provide the pilot with a remote selection of NVGs and FLIR image at will. We therefore see that the later systems combine the advantages of both the steerable and fixed FLIR systems together with the capabilities of night vision goggles.

Navigation and Map Display Systems

In addition to being able to contour fly and manoeuvre accurately at night, the pilot needs an autonomous navigation system of high accuracy in his aircraft, together with a continuous display of position. Conventional doppler and inertial navigation systems do not offer adequate accuracy. The two viable alternatives at present are ground positioning system and terrain referenced navigation system. GEC Avionics pioneered the development of TRN systems, which have the advantage of being totally autonomous. With a TRN system, the outputs from the aircraft's radio and barometric altimeters are combined to produce a profile of the terrain over which the aircraft has flown. This is compared with a stored elevation database to produce an accurate match with the aircraft's present position. Such a TRN system has been shown to have an accuracy of better than 50 metres over all normal types of terrain. In the system which has been developed by GEC Avionics, the elevation database is stored in parallel with cultural details, digitised directly from a pilot's normal low flying map. This one datastore can therefore provide all the information required for the TRN system and a digital map display in an integrated unit.

Because the databases are stored in a solid state memory store, the mean time between failure is projected to be over 1000 hours and the power requirements are minimal. The use of efficient compression algorithms ensures that the cost for storing digital map and elevation database information is less than that using optical disks, with their attendant mechanical problems. The quality of such a digital map display can be as good as a paper chart (See Figure 7). The system has the further advantage that the colour palette for the digital map can be changed at will by the crew. This means that a different colour palette can be used by night than by day, ensuring full compatibility with NVG lighting systems.

Terrain Avoidance

The same elevation database can also be used for other modes of terrain avoidance. The first method to improve the pilot's ability to avoid the ground is known as PLATO (Pilot's low altitude terrain overlay). Since the aircraft's position, altitude and orientation are known with great accuracy, it is possible to draw ridge lines and contours ahead of the aircraft's position. This can be displayed on either a head up display or helmet mounted display overlaid on the FLIR image, so that it accentuates ground features which may be hard to detect on the FLIR (See Figure 8). This enables the pilot to continue visual flight in conditions of marginal visibility, when he would normally have to pull up.

A further refinement comes from the use of the elevation database and the TRN derived position to offer full covert terrain following. With this system, the contours ahead of the aircraft's position are known with great accuracy, so that a terrain following signal can be derived, analogous to a TFR signal, but without the radar emissions. This TF signal can either drive a manual indicator on the pilot's head up display, or can be used as an input to an automatic flight control system to give full hands off terrain following. GEC Avionics has demonstrated a TRN and TF system on a British Aerospace Tornado GR.1 aircraft. The aircraft made repeated flights through the Welsh mountains at high speed and low level, fully hands off without the use of any forward looking sensor. When added to the night vision and navigation systems already described, the result is a highly automated system which is totally covert, apart from the radio altimeter. To ensure that even this signal is effectively suppressed, GEC Sensors has developed a covert radio altimeter, which uses novel techniques to make its emissions virtually undetectable.

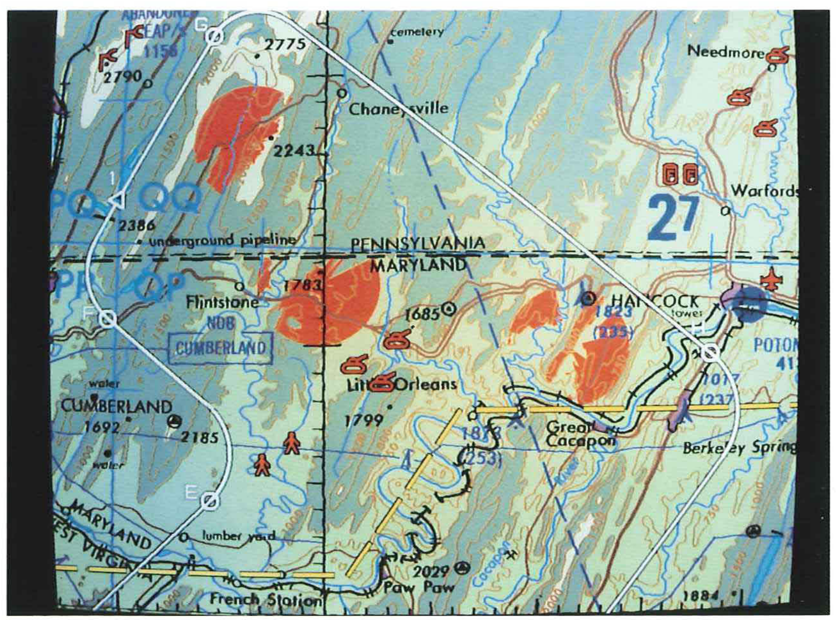


Figure 7

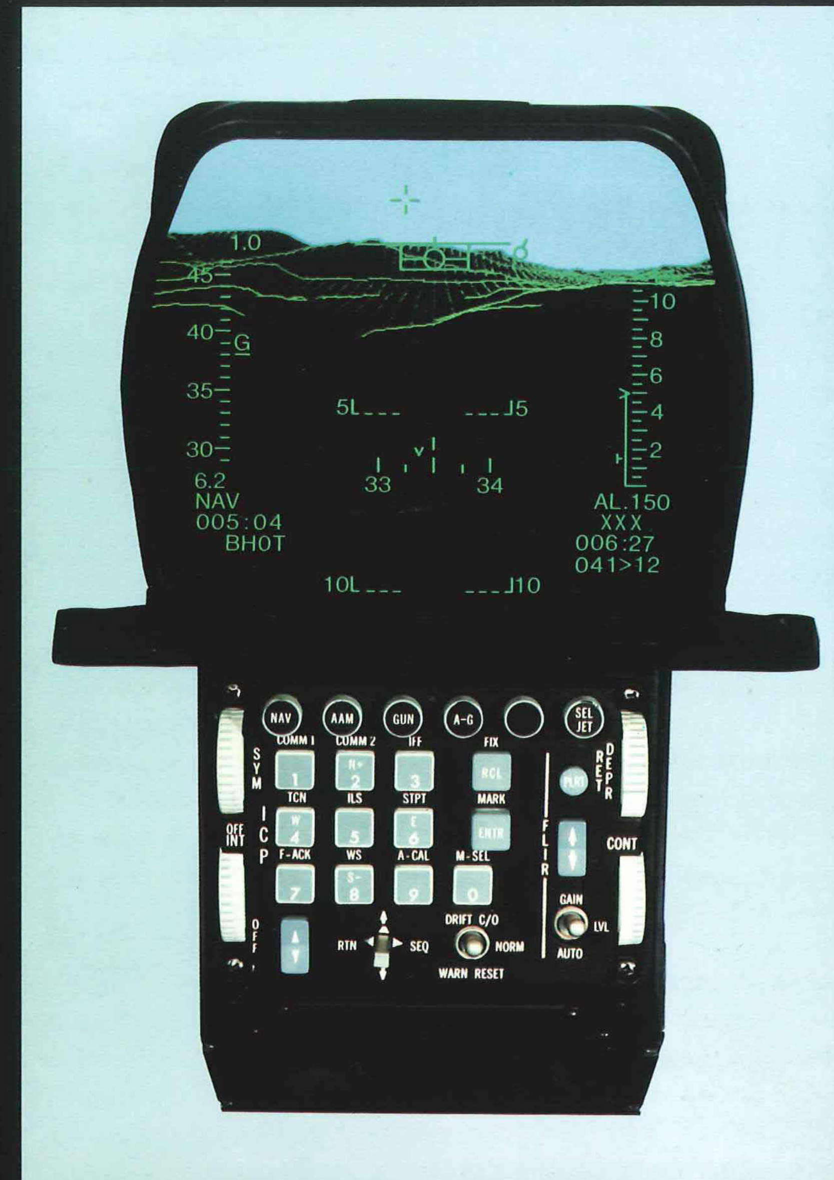


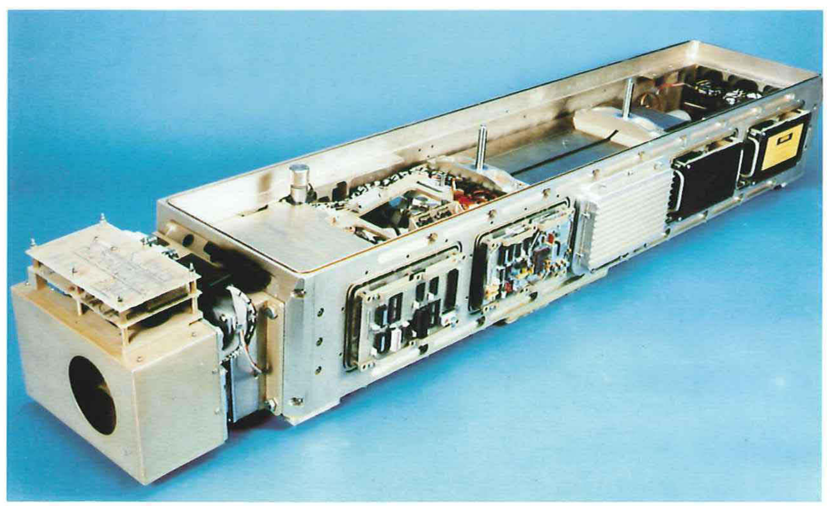
Figure 8

Obstruction Avoidance

The one remaining problem for such a system is that of avoiding vertical man-made obstructions. The faster and lower the aircraft flies, the more demanding becomes the pilot's requirement to be able to see vertical obstructions ahead of the aircraft. With existing systems, the limiting operational factor may well be the degree to which high tension cables and other vertical obstructions are known on the aircraft's track. A number of approaches have been tried to deal with this problem. One simple technique, developed by RAE Farnborough, includes a store of vertical obstructions in the aircraft's elevation database. In this way it is possible to draw visual markers overlaid on the pilot's FLIR image to indicate to him where he can expect to see masts, powerlines and other obstructions. Although this is effective, it is clearly limited by the degree to which obstructions are known in advance. It does not take account of operations in unknown territory. An alternative approach which has been tried is to detect the electro magnetic field around high tension cables. Although feasible, this has too many limitations to provide a full answer. The range of such detection is limited, it only works against high tension cables which have current flowing in them, and it is obviously totally ineffective against other types of vertical obstruction. The third possibility is to use an active sensor to detect obstructions. The best known of these systems used are millimetre wave radar and laser radar. Millimetric wave radar systems have been shown to be effective in many instances, but have some major disadvantages. In particular, although their detection range is lower than conventional radars, they are still active systems which can be detected to give warning of the aircraft's approach. Millimetric wave radar systems also rely on the structure of high tension cables to increase the detection range. They are therefore less effective against all types of cable.

The system developed by GEC Avionics uses a CO_2 laser radar (See Figure 9). This emits 50,000 pulses a second scanning an area around the aircraft's velocity vector. Whenever a laser return from a high tension cable or vertical obstruction is detected, a white pixel is illuminated in the FLIR image, on either the HUD or the helmet display. This return is stored in memory and drifts down the image at an appropriate rate for aircraft speed, angle and direction. In this way a series of returns indicates an image of the obstruction overlaid on the FLIR within a fraction of a second. This real-time obstruction display enables the pilot to pull up over or go around the obstacle. In flight trials with the US Navy, the CO_2 laser radar proved effective in detecting normal high tension cables at ranges up to 2.5 kilometres. Flight and ground trials have shown that the CO_2 laser system is effective in detecting all types of obstruction and cable in a wide range of environmental conditions. Although the system is still in an early stage of development, the potential for combining such a system with ranging, terrain following and automatic target recognition systems is considerable. Although such a pulsed CO_2 laser system is active, in practice it will be virtually undetectable and unjammable, because of the high rate of pulsing and the small footprint of the laser signal.

Figure 9



System Integration

The final and crucial stage of making a covert avionics system effective is the system integration. The effectiveness and safety of a covert system are largely dependent on how the individual components of that system are combined and integrated together. GEC Avionics demonstrated the potential for covert avionics in Project Real Night, a Foreign Weapons Evaluation Program which it undertook over a period of two and a half years for the United States Navy at NATC, Patuxent River. On this trial, the full range of covert avionics systems described to date was combined and integrated onto an A-6E Intruder aircraft (See Figure 10). Night vision was provided by a forward looking navigation FLIR, a raster head up display and Cats Eyes night vision goggles. Target acquisition was achieved by a combination of wide angle navigation FLIR and narrow field of view steerable targetting FLIR. A full digital terrain system, comprising a digital map, terrain referenced navigation and covert terrain following systems was installed. The LOCUS CO_2 laser radar was also demonstrated at the end of the trial. The pilot and navigator were able to simultaneously see the navigation FLIR with symbology and LOCUS overlay, the targetting FLIR and the digital map. Touch sensitive colour displays were installed to allow the crew to control their systems quickly. A range of colour palettes was provided for the navigator to select on the digital map. All of these systems were provided by GEC Avionics and GEC Sensors, and the complete system design and integration was by GEC Avionics. The potential for complete system integration was shown in that all of the digital map, navigation, terrain following and many display functions and laser radar processing were combined in a single card rack. This greatly reduced the weight, space and cost requirements for such a system.

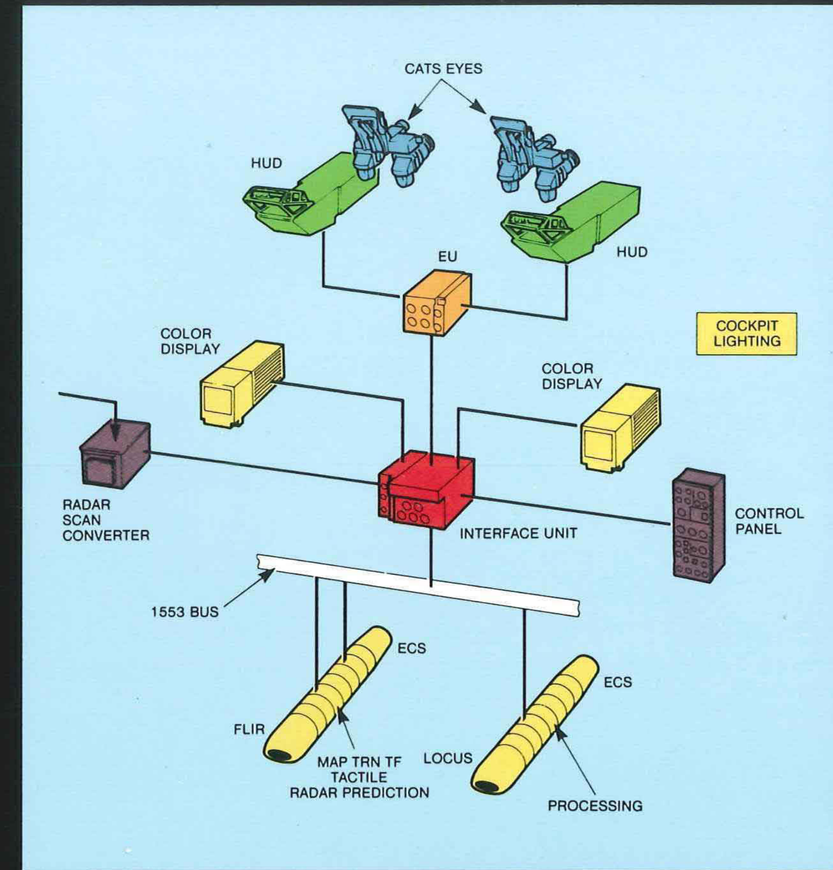


Figure 10

Present and Future

Covert low level avionics have been shown to be a reality. They exist now and are in production status. Raster head up display and FLIR systems are entering service on the AV-8B Harrier, the F-18 and the Tornado. Cats Eyes night vision goggles are in production for all types of fixed wing aircraft in the US Marine Corps and the US Navy. GEC Avionics' digital map is in production for the RAF Harrier GR.7, and its TRN/TF system has been selected for production for the RAF Tornado midlife update, as has the GEC Sensors covert radio altimeter. GEC Avionics' new integrated helmet displays will shortly be commencing flight trials on the F-18, the F-16 and the V-22 aircraft. The combination of helmet mounted displays with steerable pilot night vision FLIR is being assessed by the United States Air Force for the F-16 CAS/BAI mission. Only the laser radar is still in developmental status, and it has clearly demonstrated its potential.

So what is the next step in the development of such systems? We envisage the integration of processing for all the components of a covert avionics system such that it becomes one fully integrated system, with one avionics LRU operating a wide range of sensors and displays. With the achievement of this final stage, we will have seen the culmination of a revolution in low level tactical warfare, which started 15 years ago with a simple low light TV system in the RAE Hunter. Few people could have envisaged the consequences of this radical new approach to air warfare.

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